

RE-INTERPRETATION OF “BAR SLOWDOWN AND THE DISTRIBUTION OF DARK MATTER IN BARRED GALAXIES” BY ATHANASSOULA

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ABSTRACT

Athanassoula (2014) has claimed that measurements of the ratio of corotation radius to bar length in galaxies do not place a constraint on the disk to halo mass ratio. Her conclusion was based on a series of simulations published by Athanassoula et al. (2013). Here we show that these results are, in fact, consistent with previous work on the slow down of bars due to dynamical friction because gas inflow rearranges the disk mass before the bar settles. It therefore remains true that a bar rotating sufficiently fast that corotation is not far beyond the bar end requires a near maximum disk.

Subject headings: galaxies: kinematics and dynamics – galaxies: dark matter content

1. CONTEXT

The issue of whether the baryonic material in galaxy disks does, or does not, contribute most of the central attraction is important for many reasons, such as understanding the dynamical structure of galaxies and comparison with predictions from galaxy formation models. While the total central attraction is determined by the rotation curve, the relative contributions of baryonic and dark matter are not easily separated. Various indirect arguments have been advanced to bear on this issue, one of which is that strong bars in sub-maximal disks should be slowed by dynamical friction (Debattista & Sellwood 2000). Since R_c , the radius of corotation for a bar, increases as the bar slows, we proposed an observationally accessible measure of whether a bar has been slowed by friction as the value of the dimensionless ratio $\mathcal{R} = R_c/a_B$, where a_B is the semi-major axis of the bar. We argued that a strong bar can remain fast, $\mathcal{R} \lesssim 1.4$, only if the barred disk is close to maximal.

However, this argument was called into question in a recent paper by Athanassoula (2014) who reported \mathcal{R} values from a suite of 15 simulations with initial disk gas fractions ranging from 0 to 100% in halos that were axisymmetric, as well as similar models with mildly or strongly triaxial halos. She concluded “The models, by construction, have roughly the same azimuthally averaged circular velocity curve and halo density and they are all submaximal, i.e. according to previous works they are expected to have all roughly the same \mathcal{R} value, well outside the fast bar range (1.2 ± 0.2). Contrary to these expectations, however, these simulations end up having widely different \mathcal{R} values, either within the fast bar range, or well outside it. This shows that the \mathcal{R} value can not constrain the halo density, nor determine whether galactic discs are maximal or submaximal.”

Here we show that these statements reflect a simple misunderstanding of the criterion, and that her results appear to be in good agreement with it.

2. THE EVIDENCE

The claims by Athanassoula (2014) were based on calculations that were described more fully in Athanassoula et al. (2013). They all began with identically the same mass distribution, except that the disk was composed of different fractions of gas and star particles, and the spherical halo in one set was distorted into mildly and more strongly triaxial shape in the other two sets. At the outset, the disk was clearly submaximal, since the peak circular speed from the disk was fractionally less than the circular speed from the halo at the same radius.

The simulations lacking any gas, formed large ($a_B \sim 10$ kpc), strong bars that were fiercely braked by dynamical friction against the halo, so that $\mathcal{R} \gg 1.4$ by the end of the simulation. It is clear from Fig. 1 of Athanassoula (2014), reproduced here in the upper panel of our Fig. 1, that the final \mathcal{R} values decreased systematically with increasing gas fraction.

However, as shown in the lower panel of our Fig. 1, which is reproduced from Fig. 16 of Athanassoula et al. (2013), the mass distribution in the disks with gas was rearranged within the first 2 Gyr of evolution, well before the bars had formed and settled. The mass that accumulated in the inner disk increased with the gas mass fraction, and in the cases that began with 100% gas (magenta lines) the mass within 1 kpc increased some 4-fold over that at the start. The other simulations start with smaller gas fractions, and larger stellar fractions (the initial stellar fraction is omitted in their Figure), and therefore the relative increase in the total inner disk mass is proportionately less.

This initial rearrangement of the mass distribution is sufficient to change the dynamical properties of the models. For example, if the 100% gas disk were to have contracted homologously to an exponential disk of half the radial scale but the same total mass, then the central surface density would increase 4-fold, have a peak in the circular speed that is $\sqrt{2}$ times higher than before lying at a radius that is half that of the original peak. From

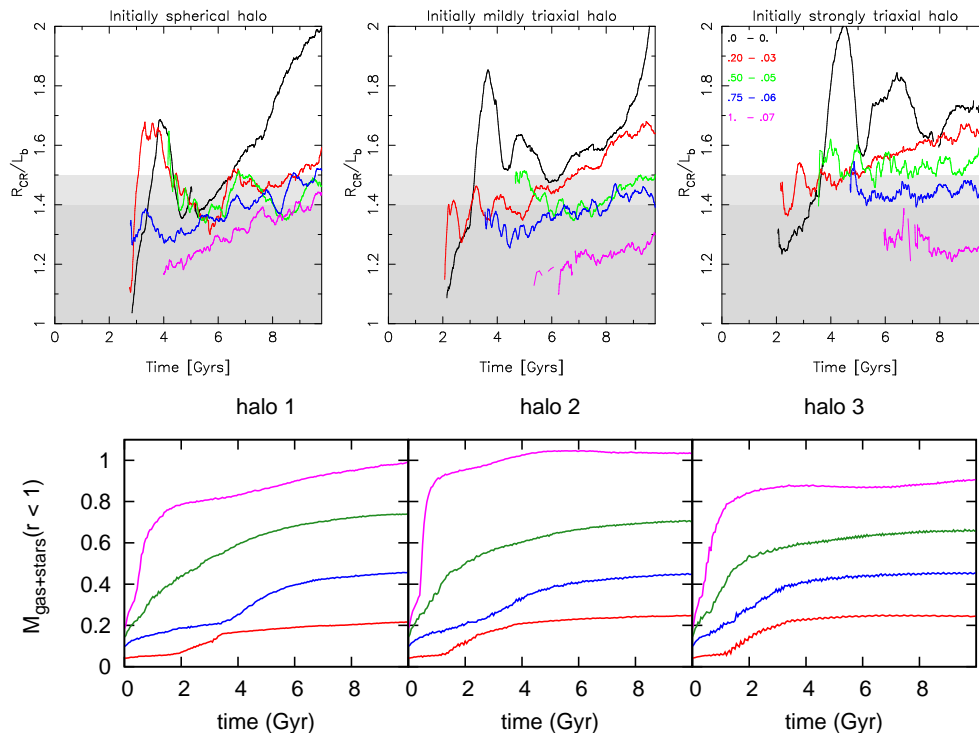


FIG. 1.— Above, Figure 1 reproduced from Athanassoula (2014), showing the time evolution of her measurements of \mathcal{R} in all 15 of her simulations. Below, Figure 16 from Athanassoula et al. (2013) showing the time evolution of the gas+new star particles inside $R = 1$ kpc in the same simulations. The red and magenta lines relate to the same models in both rows of figures, but the blue and green lines relate to models that have been interchanged between the two rows.

Fig. 1 of AMR13, that would mean the disk contribution reaches ~ 200 km/s at $R = 3.3$ kpc, which would clearly be maximal.

The contraction is unlikely to be homologous, but this crude approximation is perhaps consistent with the initially gas-rich models forming shorter bars. The size of the bar that forms in a simulation is determined by a variety of factors, including the steepness of the inner rise in the rotation curve and the distribution of mass in the disk. The bar in the model with 100% gas has $a_B \sim 5$ kpc in the spherical halo (Athanassoula 2014, her Fig. 2) about half that in the stars only case, and the decreasing bar sizes can also be seen in the snapshots of Figs. 4 & 5 and the measurements in Fig. 9 of Athanassoula et al. (2013).

It is therefore no surprise that the shorter bars in the increasingly dominant disks experience weaker friction, such that \mathcal{R} manifests the trend shown in the upper panel of Fig. 1. It seems very likely that the bars that experience little frictional drag are effectively in maximum disks.

Note also that the initial rise in the central gas density was greater in the models with triaxial halos. The principal consequence of triaxiality is to promote the inflow of gas, which is borne out by the mass increase by $t = 2$ Gyr in all cases except for the 100% gas case, which is less in the strongly triaxial case than in the mildly. This odd result could simply be stochasticity

(Debattista & Sellwood 2000) that could be checked in multiple runs with different random seeds.

3. CONCLUSIONS

Once the mass rearrangement, due to the initial shrinking size of the gas component, is taken into account, the simulations reported by Athanassoula et al. (2013) and Athanassoula (2014) appear to be consistent with all previous work (see Sellwood 2014, for a review). The different \mathcal{R} values at the ends of her 15 simulations can be understood as reflecting the differences in the effective degree of disk domination in the inner parts of the models. Thus it would appear that her results are in agreement with the conclusion that only maximal disk models can have $\mathcal{R} \sim 1.2 \pm 0.2$ after some period of evolution.

The statements to the contrary in Athanassoula (2014) seem to reflect a simple misunderstanding by that author of what exactly is the criterion. In fact, it relates to the mass distribution in the model at the time of the measurement, which is the only observationally accessible measurement, of course. Her mis-statements derive from an incorrect expectation that models that begin from the same mass distribution, but with differing fractions of gas, should all experience the same dynamical friction; in fact, the mass rearrangement in the early part of the evolution makes the gas-rich disks more nearly maximal, leading to correspondingly weaker friction on the bar that subsequently forms.

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